

**PCI Express™
Connector High Speed
Electrical Test Procedure
Revision 1.0**

July 19, 2002



Revision	Revision History	DATE
1.0	Initial release.	7/19/02

PCI-SIG disclaims all warranties and liability for the use of this document and the information contained herein and assumes no responsibility for any errors that may appear in this document, nor does PCI-SIG make a commitment to update the information contained herein.

Contact the PCI-SIG office to obtain the latest revision of this specification.

Questions regarding the PCI Express Base Specification or membership in PCI-SIG may be forwarded to:

Membership Services

www.pcisig.com

E-mail: administration@pcisig.com

Phone: 1-800-433-5177 (Domestic Only)
+503-291-2569

Fax: 503-297-1090

Technical Support

techsupp@pcisig.com

DISCLAIMER

This PCI Express Connector High Speed Electrical Test Procedure is provided "as is" with no warranties whatsoever, including any warranty of merchantability, noninfringement, fitness for any particular purpose, or any warranty otherwise arising out of any proposal, specification, or sample. PCI-SIG disclaims all liability for infringement of proprietary rights, relating to use of information in this specification. No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted herein.

PCI Express is a trademark of PCI-SIG.

All other product names are trademarks, registered trademarks, or servicemarks of their respective owners.

Contents

1. INTRODUCTION	5
1.1. REFERENCE DOCUMENTS	5
2. RECOMMENDED EQUIPMENT LIST	5
3. TEST FIXTURE DESCRIPTION	6
4. VECTOR NETWORK ANALYZER SETTINGS	8
5. CALIBRATION	8
5.1. TWO-PORT SOLT CALIBRATION KIT (AGILENT 8720ES).....	9
5.1.1. <i>Loading the Cal Kit into the Network Analyzer</i>	9
5.1.2. <i>SOLT Calibration Procedure</i>	9
5.2. FOUR-PORT SOLT CALIBRATION (AGILENT 8720ES WITH N4418A MULTI-PORT TEST SET)	11
5.2.1. <i>SOLT Calibration Procedure</i>	11
5.3. VERIFICATION OF CALIBRATION	12
5.3.1. <i>Two-port Calibration Verification</i>	12
5.3.2. <i>Four-port Calibration Verification</i>	12
6. PERFORMING THE INSERTION LOSS MEASUREMENT	12
6.1. FOUR-PORT NETWORK ANALYZER MEASUREMENT	12
6.2. TWO-PORT NETWORK ANALYZER MEASUREMENT	13
7. RETURN LOSS MEASUREMENT	14
7.1. FOUR-PORT VECTOR NETWORK ANALYZER MEASUREMENT	14
7.2. TWO-PORT VECTOR NETWORK ANALYZER MEASUREMENT	15
8. NEAR-END CROSSTALK MEASUREMENT	15
8.1. PORT DEFINITION.....	15
8.2. NEXT MEASUREMENT PROCEDURE	16
8.2.1. <i>Four-port Vector Network Analyzer Measurement</i>	17
8.2.2. <i>Two-port Vector Network Analyzer Measurement</i>	18

9.	SINGLE ENDED MODE TO DIFFERENTIAL MODE POST-PROCESSING	20
9.1.	DERIVATION OF DIFFERENTIAL S-PARAMETERS FROM SINGLE ENDED S-PARAMETER DATA	20
9.1.1.	<i>Definition of S-parameters</i>	20
9.1.1.1.	Incident and Reflected Waves	20
9.1.1.2.	Derivation of Differential S-parameters	24
9.2.	EXTRACTION OF DIFFERENTIAL S-PARAMETERS FROM SINGLE ENDED MEASUREMENTS	26
9.2.1.	<i>Four-port Differential S-parameter Extraction–Insertion Loss</i>	26
9.2.2.	<i>Two-port Differential S-parameter Extraction–Insertion Loss</i>	27
9.2.3.	<i>Four-port Differential S-parameter Extraction–Return Loss</i>	28
9.2.4.	<i>Two-port Differential S-parameter Extraction–Return Loss</i>	28
9.2.5.	<i>Four-port Differential S-parameter Extraction–NEXT</i>	29
9.2.6.	<i>Two-port Differential S-parameter Extraction–NEXT</i>	30

Figures

FIGURE 1:	PCI EXPRESS CONNECTOR TEST FIXTURE	6
FIGURE 2:	PICTURE OF EDGE FINGER WITH GROUND PLANE REMOVED UNDER PADS.....	7
FIGURE 3:	INSERTION LOSS & RETURN LOSS STRUCTURE.....	13
FIGURE 4:	PORT DEFINITION DIAGRAM FOR NEAR-END CROSSTALK.....	16
FIGURE 5:	TEST STRUCTURE FOR NEAR-END CROSSTALK	17
FIGURE 6:	DEFINITION OF WAVE VARIABLES	21
FIGURE 7:	CONVENTION USED FOR PORT VOLTAGE AND CURRENT	22
FIGURE 8:	CONVENTION FOR NUMBERING PORTS.....	22
FIGURE 9:	TWO DIFFERENTIAL TRANSMISSION LINE PAIRS WITH PORT NUMBERING.....	23
FIGURE 10:	APPLYING DIFFERENTIAL STIMULUS TO PORTS 1 AND 3	24
FIGURE 11:	MAPPING AN EIGHT-PORT DEVICE INTO A DIFFERENTIAL FOUR-PORT DEVICE	25

Tables

TABLE 1:	BASELINE VNA SETTINGS	8
----------	-----------------------------	---

1. Introduction

This test procedure outlines the steps required to perform high speed signal integrity measurements on a PCI Express connector. The high speed signal integrity requirements are described in the connector specification section (Chapter 5) of the *PCI Express Card Electromechanical Specification*.

1.1. Reference Documents

This document follows the procedures outlined in ANSI Electronics Industry Alliance (EIA) standards documents:

- ❑ *EIA 364-101 – Attenuation Test Procedure for Electrical Connectors, Sockets, Cable Assemblies or Interconnection Systems*
- ❑ *EIA 364-90 – Crosstalk Ratio Test Procedure for Electrical Connectors, Sockets, Cable Assemblies or Interconnection Systems*
- ❑ *EIA 364-108 – Impedance, Reflection Coefficient, Return Loss, and VSWR Measured in the Time and Frequency Domain Test Procedure for Electrical Connectors, Sockets, Cable Assemblies or Interconnection Systems*

2. Recommended Equipment List

The following equipment is recommended to give the best measurement accuracy and has been verified to be compatible with this test procedure and the test fixture:

Vector Network Analyzer: Agilent (HP) 8753E, 8720ES, 8510 or equivalent

Calibration Kit: 85052D or equivalent

Coaxial Terminations: Pomona 4286 or equivalent

The coaxial terminations have a direct effect on the results of the measurements. The performance of the coaxial termination across the measurement frequency range must be verified before proceeding.

The Agilent N4418A balanced measurement S-parameter test set is used to develop the four port measurement procedures. Since the N4418A is controlled by software on a host computer, the procedure contains specific instructions for using this specific equipment setup. However, since the transformation to differential S-parameters is done by a post-processing step, this procedure can be extended for use with other balanced measurement equipment.

3. Test Fixture Description

This test procedure is developed for use with the PCI Express Connector Qualification Board that is shown in Figure 1. The test fixture is designed and should be built to specific criteria, as described below, to ensure good measurement accuracy and compatibility with the interconnect specifications.

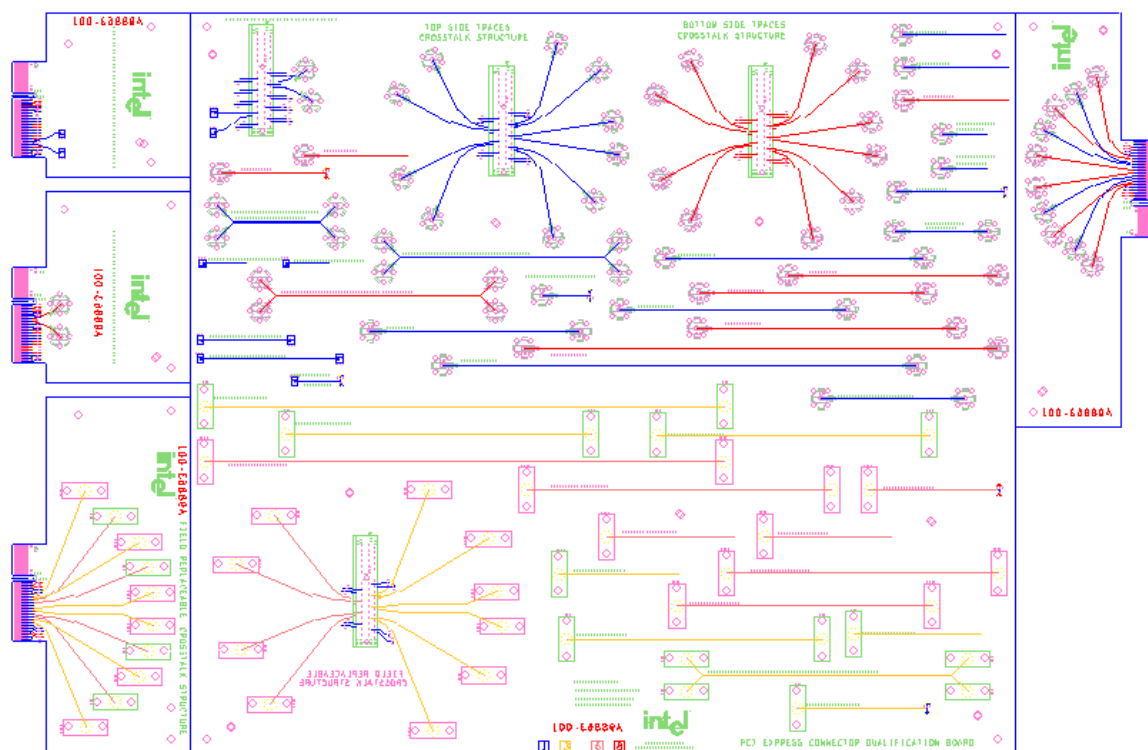


Figure 1: PCI Express Connector Test Fixture

Because of the requirements by the spacing between coaxial connectors and trace length, the test fixture implements two different test structures. One test structure is used for measuring near-end crosstalk while the other test structure is used to measure the insertion loss and the return loss. Several other structures are also placed on the board for reference. But this test procedure focuses only on these two structures.

The microstrip traces on the test board and the add-in card must be designed to minimize their impact on the measurement of the differential characteristics of the connector. One requirement is to keep the traces uncoupled from each other. Therefore, the test traces must be routed such that they do not couple to each other, any other test structure, or metal feature. Test traces shall be placed as far apart as physically allowable while simultaneously satisfying the trace length requirements. For the insertion loss/return loss test structure, the test fixture includes 600 mils of microstrip trace on the test board and another 600 mils of microstrip trace on the add-in card. This length of line becomes part of the measurement and therefore must be maintained as a standard length for the test structure. Note that the edge finger pad is not counted as the add-in card PCB trace—it is considered as a part of the connector interface.

The near-end crosstalk test structure requires longer traces to keep the coaxial SMA connectors separated by a minimum of 450 mils center-to-center. This requirement for SMA spacing is necessary to allow connection to the network analyzer cables. The resulting trace length for the test structure is roughly 1.5 inches. Although this is significantly more than the trace length for the insertion/return loss structure, the near-end crosstalk measurement is less sensitive to the trace length as long as the traces are uncoupled.

The vector network analyzer setup used in this procedure performs S-parameter measurements using a 50 Ω reference impedance. Therefore, all of the test traces must be held to a characteristic impedance of 50 Ω with a tolerance of $\pm 5\%$. This is especially critical for performing the return loss measurement since the test trace becomes part of the measurement and return loss is sensitive to the impedance seen by the network analyzer.

The physical design of the test board and add-in card also play a role in determining the performance of the connector. The add-in card edge finger is generally more capacitive than the test traces connected to it so it also has a lower impedance associated with it. This is because the metal pads in effect form parallel plate capacitors with the ground plane directly underneath them on the add-in card. To minimize this capacitive impact, the ground plane shall be removed underneath the edge fingers on the add-in card as shown in Figure 2. This reflects a typical implementation of the add-in card ground plane design.

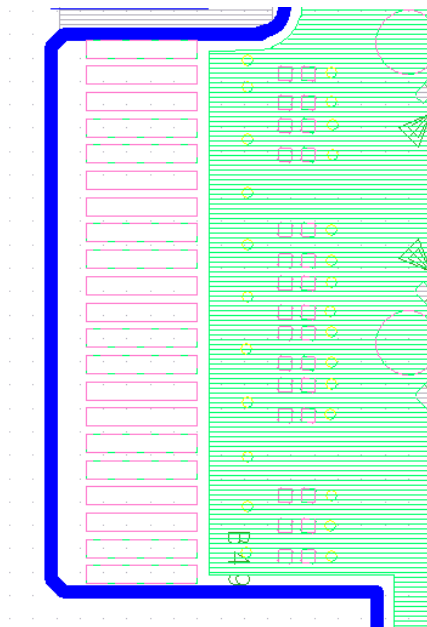


Figure 2: Picture of Edge Finger with Ground Plane Removed Under Pads

On the test board side, the design of the connector footprint symbol is also a significant performance consideration. In this case, the through hole pad stack-up follows a typical through hole mount connector implementation. The recommended size of the anti-pad corresponding to the plated through holes on the test board is 58 mils in diameter. The large anti-pad is used to reduce the capacitance of the through hole. The pads on the plated through holes are 42 mils in diameter and the plated through holes themselves are 28 mils finished. Finally, there is no thermal relief on the plated through holes connected to the ground/power planes.

The test fixture (board plus card) Gerber files are available from the PCI-SIG website for download.

4. Vector Network Analyzer Settings

The state of the vector network analyzer (VNA) affects the measurement and calibration performance. In order to improve accuracy and repeatability for connector measurements, it is necessary to use the baseline settings shown in Table 1 in combination with the calibration procedure.

Table 1: Baseline VNA Settings

VNA Setting	Value
Frequency Range:	100 MHz to 4 GHz
Number of Points	801
Number of Averages	8
IF Bandwidth	300 Hz

5. Calibration

To properly characterize the performance of the connector in the test fixture, the VNA must be calibrated to a known standard. The intent of the calibration is to eliminate systematic errors in the measurement system to improve the measurement accuracy. Variations in the test equipment and test conditions as well as the measurements themselves can cause errors in the measurement. Thus, the goal of the testing is to minimize this error to within acceptable limits. Therefore, to ensure each measurement has acceptable accuracy and repeatability, it is recommended to follow these procedures for calibrating the network analyzer.

ESD CAUTION

The VNA is very sensitive to static.
Make sure to always use the Ground Strap whenever working with the VNA.

Before beginning the calibration, reset the VNA by pressing the “Preset” hard key button. This returns the VNA to a factory pre-defined state and ensures that all of the analyzer settings are based on this state.

5.1. Two-port SOLT Calibration Kit (Agilent 8720ES)

5.1.1. Loading the Cal Kit into the Network Analyzer

The vector network analyzer uses programmable coefficients specific to each different type of calibration and its corresponding test set. These coefficients may be programmed by hand, but the 3.5 mm calibration described in this procedure is one of the default calibration kits that can be chosen under the calibration menu. Therefore, all that must be done is to verify that the correct 3.5 mm calibration kit is selected.

There may be a couple variations of the 3.5 mm calibration kit. Some calibrations require a sliding load for measurements over a broad frequency range. In this case, the calibration kit that uses a single broadband coaxial load should be chosen. For the Agilent VNA model 8720ES, the corresponding calibration kit is “3.5mmD” which is reflected in this procedure. However, the specific kit name may vary with the VNA model and type.

5.1.2. SOLT Calibration Procedure

Legend: (HK) = Hard Key Menu option
(SK) = Soft Key Menu option

1. Set Start/Stop Frequency
 - (HK) Start
 - (HK) 100 M/u (100 MHz)
 - (HK) Stop
 - (HK) 10 G/u (10 GHz)
2. Number of Points
 - (HK) Sweep Setup
 - (SK) Number of Points 801 X1 (801 points)
3. Turn on Averaging and Set Number of Averages
 - (HK) Avg
 - (SK) Averaging (ON)
 - (SK) Averaging Factor 8 X1 (8 averages)

4. Set IF Bandwidth and System Z0
(SK) IF BW 300 X1 (300 Hz)
(SK) Smoothing (OFF)
5. Set Impedance to 50 Ω
(HK) Cal
(SK) More
(SK) Set Z0 50 X1 (50 Ω)
(SK) Return
6. Turn on Interpolation ON and Correction OFF
(HK) Cal
(SK) Interpolation ON
(SK) Correction OFF
7. Select Cal Kit
(HK) Cal
(SK) Cal Kit
(SK) Select Cal Kit
(SK) More
(SK) 85052D
(SK) Return
(SK) Return
(SK) Save Cal Kit
8. Floppy Disk Save Setup
(HK) Save/Recall
(SK) Select Disk
(SK) Internal Disk
(SK) Return
(SK) Define Disk Save
(SK) Data Array ON
(SK) Data Only ON
(SK) ASCII

5.2. Four-port SOLT Calibration (Agilent 8720ES with N4418A Multiport Test Set)

5.2.1. SOLT Calibration Procedure

1. Initial Computer Setup

- a. Double click the Multiport software icon.
- b. Click on Calibrate and select Standard Calibration from the drop down menu.
- c. Enter 100 MHz start frequency, 10000 MHz stop frequency, and 10 MHz step size.
- d. Power 5 dBm, Slope 0 dB/G, Attenuation n/a.
- e. Averaging values Cal = 1, Measure = 1.
- f. Set IF Bandwidth = 300 Hz.
- g. Select Stepped Sweep Mode.
- h. Click on OK.

Note: If you receive an error message, the VNA may have been used in two-port mode recently. Simply repeat the initial setup to have the GPIB connection assume control.

2. Select Cal Kit

- a. Select 3.5 mm HP85052D for each port.
- b. Select Coaxial Standards.

3. Select Thru Configuration

- a. Select Configuration 1, 2, or 3 as per your preference.
- b. Set Phase Rotation to 0 picoseconds.
- c. Click on Use in All Valid Positions and verify all thru check boxes have a check mark in them.
- d. Check mark Interpolate Data if necessary.
- e. Click on OK.

4. Follow the On-screen Menu and Press Finish to Save Cal When Done

5. Saving and Exporting Data

- a. Click File, select Save, then select data.
- b. Enter your file name and click save.
- c. Click File, select Export, and then select Tab Delimited File.
- d. Enter a file name and click OK.

5.3. Verification of Calibration

5.3.1. Two-port Calibration Verification

Connect the load to port 1, measure S11 in linear magnitude dB, and look for a minimum of –60 dB across the bandwidth of the measurement. You may repeat with the load on port 2, and measure S22 in the same manner. Then connect the through between ports 1 and 2, measure S12 in linear magnitude dB, and insertion loss should be less than .01 dB typically. These are only general guidelines, as cable quality, temperature, frequency range, etc. all contribute to various error terms and affect accuracy.

5.3.2. Four-port Calibration Verification

Only a small portion of the calibration of the four-port VNA is performed in the interest of time. Once the VNA calibration is complete, disconnect the load from port 4, and connect the through between ports 1 and 4. In the unbalanced display with 16 charts, select S14 and choose the linear magnitude format, then do the same with S41. The variation should be less than .01 dB with no outliers. Select S22 and choose the Smith Chart format, which should have the open connected on port 2. The measurement should start on the far right of the unit circle and curve towards the bottom along it. Select S33, which has the short on port 3, and set the display for a Smith chart. The measurement trace will begin on the left edge of the unit circle and curve along the circle towards the top. Additional verification can be done with the differential coupons on the test board.

6. Performing the Insertion Loss Measurement

A special insertion loss structure is designed to minimize the effects of the test fixture. This test structure only has one differential signal pair available for measurement. All of the adjacent differential signal pairs are terminated to 50 Ω resistors. This setup allows the minimum test trace length to be used in the structure while still providing room for attaching the SMA cables to the board.

Figure 3 shows both the test board structure and the plug-in card for the insertion loss test. The SMA connectors are used for the insertion loss measurement.

6.1. Four-port Network Analyzer Measurement

Refer to Figure 3 for specific connection points.

1. Connect port 1 of the network analyzer to the SMA labeled J4 on the test board.
2. Connect port 2 of the network analyzer to the SMA labeled J37 on the card.
3. Connect port 3 to J9 on the test board.
4. Connect port 4 to J43 on the card.

5. Perform the four port measurement and save the resulting single ended S-parameters (untransformed) to 4pS21.s1.

Extract the differential transmission parameter DDS21 as outlined in Section 9.2.1. The parameter DDS21 versus frequency is the insertion loss measurement desired.

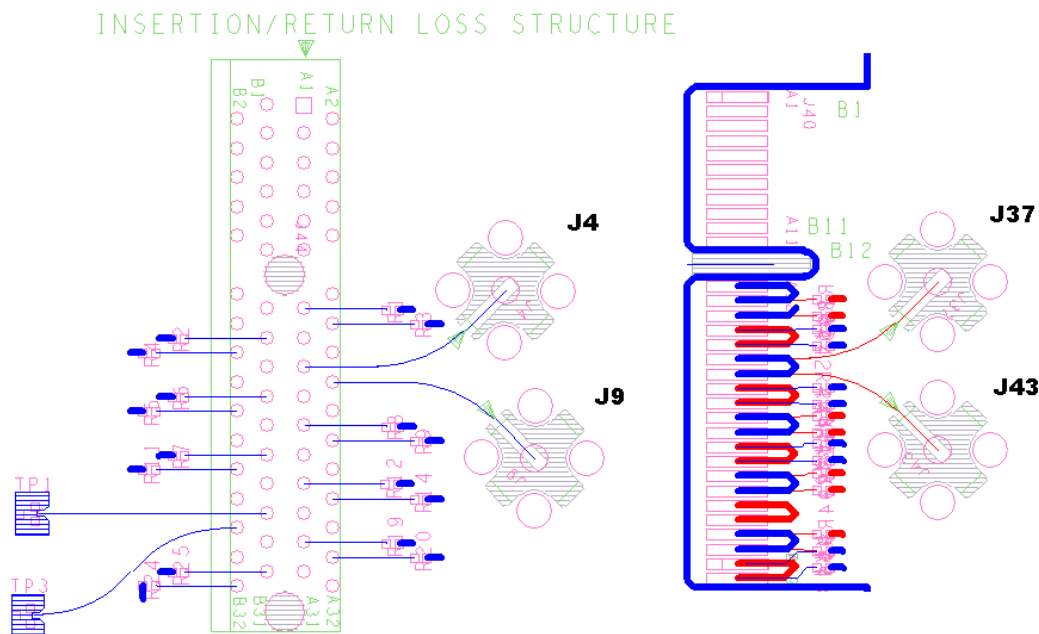


Figure 3: Insertion Loss & Return Loss Structure

6.2. Two-port Network Analyzer Measurement

There are three measurements that must be made when performing the insertion loss measurement with a two-port network analyzer. The procedure is to keep port 1 of the VNA connected to the SMA J4 while moving port 2 through the different SMA sites of the structure. It is extremely important to use high quality SMA coaxial terminations on the SMA sites that are not connected to the VNA. The high frequency performance of the terminations directly affects the quality of the measurement. Therefore, the quality of the coaxial terminations across the frequency range should be verified before proceeding.

1. Connect port 1 to the SMA labeled J4 on the test board.
2. Connect port 2 to the SMA labeled J37 on the test card.
3. Terminate SMA's J43 and J9 to 50 Ω .
4. Perform the S21 measurement and store the results to J04_J37.s1.
5. Leave port 1 connected to J4.
6. Connect port 2 to the SMA J43 on the test card.
7. Terminate SMA's J37 and J9 to 50 Ω .
8. Perform the S21 measurement and store the results to J04_J43.s1.
9. Move port 1 to J9.

10. Connect port 2 to the SMA J43.
11. Terminate SMA's J37 and J4 to 50 Ω .
12. Perform the S21 measurement and store the result to J09_J43.s1.
13. Leave port 1 connected to J9.
14. Connect port 2 to the SMA J37 on the test card.
15. Terminate SMA's J43 and J4 to 50 Ω .
16. Perform the S21 measurement and store the results to J09_J37.s1.

After the measurements are completed, extract the differential parameter DDS21 as outlined in Section 9.2.2. The parameter DDS21 versus frequency is the insertion loss measurement desired.

7. Return Loss Measurement

The insertion loss structure shown in Figure 3 is also used for measuring return loss.

7.1. Four-port Vector Network Analyzer Measurement

Refer to Figure 3 for specific connection points.

1. Connect port 1 of the network analyzer to the SMA labeled J4 on the test board.
2. Connect port 2 of the network analyzer to the SMA labeled J37 on the card.
3. Connect port 3 to J9 on the test board.
4. Connect port 4 to J43 on the card.
5. Perform the four-port measurement and save the resulting single ended (untransformed) S-parameters to 4pS11.s1.

Extract the differential transmission parameter DDS11 as outlined in Section 9.2.3. The parameter DDS11 versus frequency is the return loss measurement desired.

7.2. Two-port Vector Network Analyzer Measurement

There is one data set that must be made when performing the return loss measurement with a two-port network analyzer. It is extremely important to use high quality SMA coaxial terminations on the SMA sites that are not connected to the VNA. The high frequency performance of the terminations directly affects the quality of the measurement. Therefore, the performance of the coaxial terminations must be verified across the frequency range before proceeding.

1. Connect port 1 to the SMA labeled J4 on the test board.
2. Connect port 2 to the SMA labeled J9 on the test card.
3. Terminate SMA's J43 and J37 to 50 Ω .
4. Perform the two-port measurement and store the results to "J04_J09.s1".

After the measurements are completed, extract the differential parameter DDS11 as outlined in Section 9.2.4. The parameter DDS11 versus frequency is the insertion loss measurement desired.

8. Near-End Crosstalk Measurement

8.1. Port Definition

The measurement of near-end crosstalk for the connector uses the structure labeled "Bottom Side Traces Crosstalk Structure." Each SMA is labeled with a specific component number with a prefix of "J" just as the other structures. For example, "J89" is one of the test card SMA's. However, for extracting the differential S-parameters from the measurements, the ports are defined as shown in Figure 4.

Figure 4 is divided into three sections showing diagrams of the "A" and "B" sides of the add-in card edge finger and a diagram of the test board pin-out. The left hand side of the figure shows the edge fingers on the "B" side of the add-in card. Those edge fingers correspond to the two left hand side rows of contacts in the test board pin-out that is shown in the middle of the figure. For example, port 19 is a port on the test board that is connected to port 20 on the add-in card. A similar diagram is shown on the right hand side of the figure. For example, port 1 is at the source end of one line of the victim differential pair. It is connected via a connector pin to port 2 on the add-in card that is shown as a diagram of the edge finger on the right hand side. Port 1 and port 3 are the test board launch sites for the victim differential signal pair. The near-end crosstalk measurement includes the sum of the crosstalk from all of the other adjacent differential signal pairs on the victim pair. This includes pairs on the opposite side of the connector from the victim pair in addition to the signal pairs on either side of the victim. The port numbers for both the add-in card and the test board are defined in the figure.

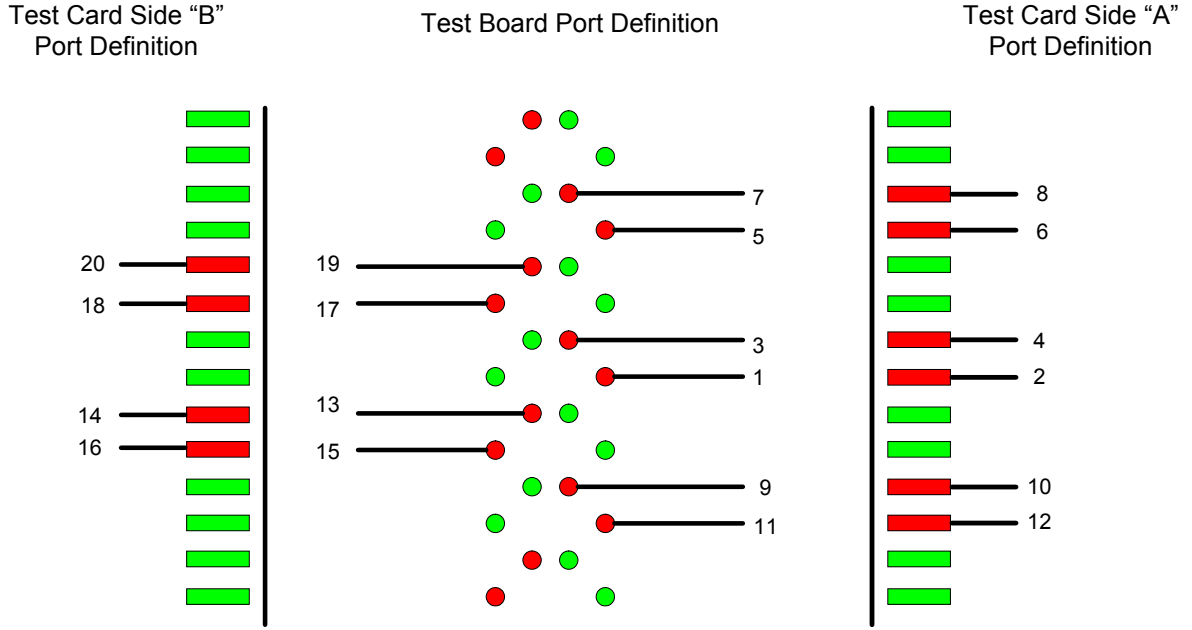


Figure 4: Port Definition Diagram for Near-end Crosstalk

For the port definition described above, the total near-end crosstalk on the victim differential pair is calculated by Equation 1 shown below:

$$DDNEXT = \frac{1}{2} (S_{5_1} + S_{9_3} + S_{13_3} + S_{17_1} + S_{7_3} + S_{11_1} + S_{15_1} + S_{19_3}) - \frac{1}{2} (S_{5_3} + S_{9_1} + S_{13_1} + S_{17_3} + S_{7_1} + S_{11_3} + S_{15_3} + S_{19_1})$$

Equation 1: Calculation of DDNEXT from Single-ended S-parameter Measurements

8.2. NEXT Measurement Procedure

The crosstalk procedure requires measurements between launch points of each differential pair. Figure 5 shows the NEXT test structure on the right hand side and the add-in card on the left. The add-in card picture shows components and traces on both sides of the add-in card. The red colored traces are on the bottom side and the blue traces are on the top. Therefore, "J74" is connected to "J86" through the connector.

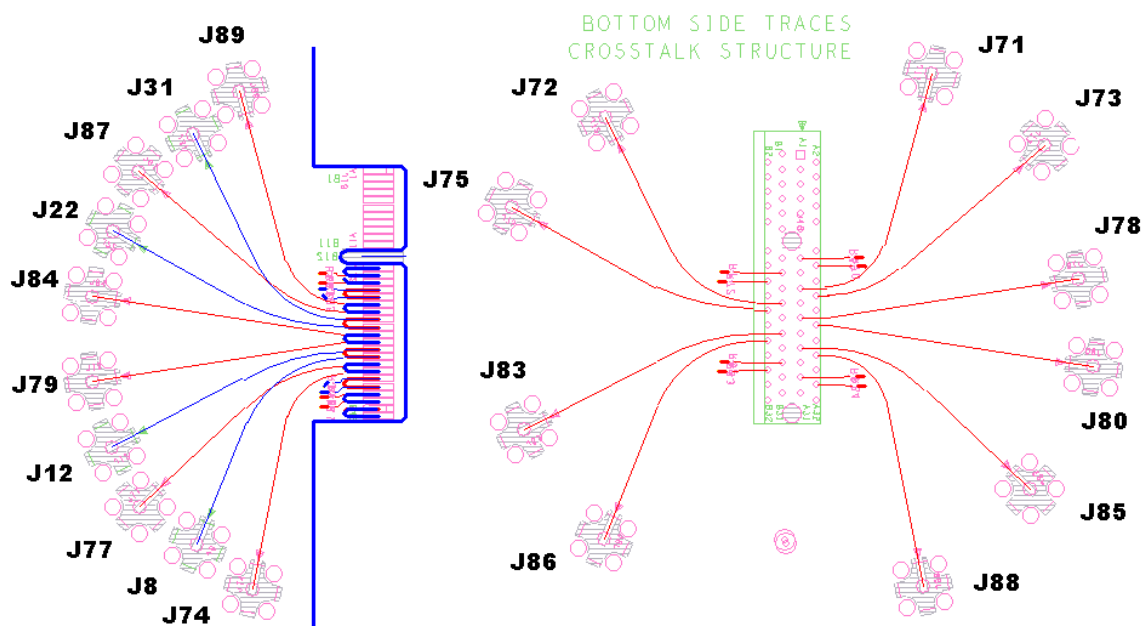


Figure 5: Test Structure for Near-end Crosstalk

8.2.1. Four-port Vector Network Analyzer Measurement

Refer to Figure 5 for the component numbers.

1. Connect port 1 of the network analyzer to the SMA labeled J78 on the test board.
2. Connect port 2 of the network analyzer to the SMA labeled J71 on the add-in card.
3. Connect port 3 of the network analyzer to the SMA labeled J80 on the test board.
4. Connect port 4 of the network analyzer to the SMA labeled J73 on the add-in card.
5. Terminate all of the other SMA's to 50 Ω .
6. Perform the four-port measurement and save the results to 4pS31.s1.
7. Leave port 1 of the VNA on J78 & port 3 of the VNA on J80.
8. Connect port 2 of the network analyzer to the SMA labeled J85 on the add-in card.
9. Connect port 4 of the network analyzer to the SMA labeled J88 on the add-in card.
10. Terminate all of the other SMA's to 50 Ω .
11. Perform the four-port measurement and save the results to 4pS51.s1.
12. Leave port 1 of the VNA on J78 & port 3 of the VNA on J80.
13. Connect port 2 of the network analyzer to the SMA labeled J83 on the add-in card.
14. Connect port 4 of the network analyzer to the SMA labeled J86 on the add-in card.
15. Terminate all of the other SMA's to 50 Ω .
16. Perform the four port measurement and save the results to 4pS71.s1.

17. Leave port 1 of the VNA on J78 & port 3 of the VNA on J80.
18. Connect port 2 of the network analyzer to the SMA labeled J72 on the add-in card.
19. Connect port 4 of the network analyzer to the SMA labeled J75 on the add-in card.
20. Terminate all of the other SMA's to 50 Ω .
21. Perform the four-port measurement and save the results to 4pS91.s1.

After the measurements are completed, extract the differential parameter DDNEXT as outlined in Section 9.2.5. The parameter DDNEXT versus frequency is the total near-end crosstalk on the victim trace desired.

8.2.2. Two-port Vector Network Analyzer Measurement

Refer to Figure 5 for the specific component numbers of the NEXT test structure.

1. Connect port 1 of the network analyzer to the SMA labeled J78.
2. Connect port 2 of the network analyzer to the SMA labeled J71.
3. Terminate all of the other SMA's to 50 Ω .
4. Perform the two port measurement and save the results to J78_J71.s1.
5. Leave port 1 of the network analyzer on J78.
6. Connect port 2 of the network analyzer to the SMA labeled J73.
7. Terminate all of the other SMA's to 50 Ω .
8. Perform the two port measurement and save the results to J78_J73.s1.
9. Leave port 1 of the network analyzer on J78.
10. Connect port 2 of the network analyzer to the SMA labeled J85.
11. Terminate all of the other SMA's to 50 Ω .
12. Perform the two port measurement and save the results to J78_J85.s1.
13. Leave port 1 of the network analyzer on J78.
14. Connect port 2 of the network analyzer to the SMA labeled J88.
15. Terminate all of the other SMA's to 50 Ω .
16. Perform the two port measurement and save the results to J78_J88.s1.
17. Leave port 1 of the network analyzer on J78.
18. Connect port 2 of the network analyzer to the SMA labeled J86.
19. Terminate all of the other SMA's to 50 Ω .
20. Perform the two port measurement and save the results to J78_J86.s1.
21. Leave port 1 of the network analyzer on J78.
22. Connect port 2 of the network analyzer to the SMA labeled J83.

23. Terminate all of the other SMA's to 50 Ω .
24. Perform the two port measurement and save the results to J78_J83.s1.
25. Leave port 1 of the network analyzer on J78.
26. Connect port 2 of the network analyzer to the SMA labeled J75.
27. Terminate all of the other SMA's to 50 Ω .
28. Perform the two port measurement and save the results to J78_J75.s1.
29. Leave port 1 of the network analyzer on J78.
30. Connect port 2 of the network analyzer to the SMA labeled J72.
31. Terminate all of the other SMA's to 50 Ω .
32. Perform the two port measurement and save the results to J78_J72.s1.
33. Move port 1 of the network analyzer to the SMA labeled J80.
34. Connect port 2 of the network analyzer to the SMA labeled J71.
35. Terminate all of the other SMA's to 50 Ω .
36. Perform the two port measurement and save the results to J80_J71.s1.
37. Leave port 1 of the network analyzer on J80.
38. Connect port 2 of the network analyzer to the SMA labeled J73.
39. Terminate all of the other SMA's to 50 Ω .
40. Perform the two port measurement and save the results to J80_J73.s1.
41. Leave port 1 of the network analyzer on J80.
42. Connect port 2 of the network analyzer to the SMA labeled J85.
43. Terminate all of the other SMA's to 50 Ω .
44. Perform the two port measurement and save the results to J80_J85.s1.
45. Leave port 1 of the network analyzer on J80.
46. Connect port 2 of the network analyzer to the SMA labeled J88.
47. Terminate all of the other SMA's to 50 Ω .
48. Perform the two port measurement and save the results to J80_J88.s1.
49. Leave port 1 of the network analyzer on J80.
50. Connect port 2 of the network analyzer to the SMA labeled J86.
51. Terminate all of the other SMA's to 50 Ω .
52. Perform the two port measurement and save the results to J80_J86.s1.
53. Leave port 1 of the network analyzer on J80.
54. Connect port 2 of the network analyzer to the SMA labeled J83.
55. Terminate all of the other SMA's to 50 Ω .

56. Perform the two port measurement and save the results to J80_J83.s1.
57. Leave port 1 of the network analyzer on J80.
58. Connect port 2 of the network analyzer to the SMA labeled J75.
59. Terminate all of the other SMA's to 50 Ω .
60. Perform the two port measurement and save the results to J80_J75.s1.
61. Leave port 1 of the network analyzer on J80.
62. Connect port 2 of the network analyzer to the SMA labeled J72.
63. Terminate all of the other SMA's to 50 Ω .
64. Perform the two port measurement and save the results to J80_J72.s1.

After the measurements are completed, extract the differential parameter DDNEXT as outlined in Section 9.2.6. The parameter DDNEXT versus frequency is the total near-end crosstalk on the victim trace desired.

9. Single Ended Mode to Differential Mode Post-Processing

This section provides all of the necessary background for extracting differential S-parameters from single ended measurements. The procedure is outlined in Section 9.2 which uses a specific file format to extract the required differential S-parameters from the single ended measurements. However, if the format specified is not accessible or incompatible with the available VNA, the following derivation may be used as a basis for developing the required equations.

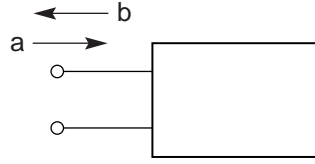
9.1. Derivation of Differential S-parameters from Single Ended S-parameter Data

9.1.1. Definition of S-parameters

9.1.1.1. Incident and Reflected Waves

Most signal integrity and microwave engineers are familiar with the concepts of transmission line theory. This derivation assumes that the reader understands the basics of transmission line theory including the meaning of incident and reflected waves. There are several texts that describe these fundamental concepts. One good reference for further background reading is *Microwave Engineering* by David Pozar.

The notation that will be used in this derivation uses the lower case letter “a” to describe the wave traveling into the referenced port and the lower case letter “b” to represent the wave traveling out of the referenced port. Figure 6 is a depiction of the wave variables.



A-0328

Figure 6: Definition of Wave Variables

In addition to wave variables, references will be made to specific parameters that are components of the wave. For example, the voltage of a wave function will be represented by the typical symbol which represents voltage, (“V”), with a superscript which describes the direction with respect to the transmission line or port. For waves traveling in the positive direction or into the referenced port, a plus sign is used. Therefore, the voltage associated with the wave function “a” will be represented by “V⁺”. Finally, if the voltage is associated with a specific port, the port number will be included as a subscript to the parameter. For example, the current traveling out of port 5 will be referenced as “I₅⁻”.

Given the above notation, the equation describing the voltage in the positive direction along a transmission line is shown in Equation 2. The definition of characteristic impedance is also shown.

$$V^+ = Z_o I^+ \Rightarrow Z_o = \frac{V^+}{I^+}$$

Equation 2: Equation for Voltage Wave in Positive Direction Along a Transmission Line

The wave variables may then be described in terms of the voltage and current components as given in Equation 3.

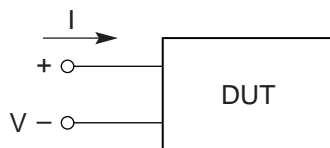
$$a_1 = \frac{V_1^+ + Z_o I_1^+}{2\sqrt{Z_o}} \quad a_2 = \frac{V_2^+ + Z_o I_2^+}{2\sqrt{Z_o}}$$

Equation 3: Wave Variable in Terms of Voltage and Current Waves

It is also important to note that the voltage is defined across the terminals of the port and the current is defined as flowing into the port as shown in Figure 7. Therefore, the current traveling out of the port has a superscript “-” to indicate the direction of the current wave and a minus sign to indicate that the magnitude is in the opposite direction than the convention used, “-I⁻”. This may seem strange, but note that it is possible to have a negative current wave traveling into the port. Therefore, the total voltage and total current at a port is defined as given in Equation 4.

$$V_T = V^+ + V^- \quad I_T = I^+ - I^-$$

Equation 4: Total Voltage and Current in Terms of Wave Parameters



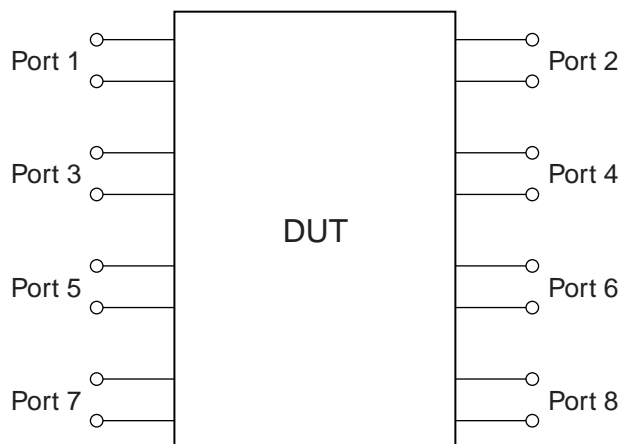
A-0329

Figure 7: Convention Used for Port Voltage and Current

At this point it is convenient to introduce the concept of a differential wave variable. Most signal integrity and microwave engineers are familiar with wave variables as defined in the single ended sense. However, we can also define wave variables in the case of a differential mode. The differential voltage will be defined here as the difference in single ended voltages between the two transmission lines which form the differential pair.

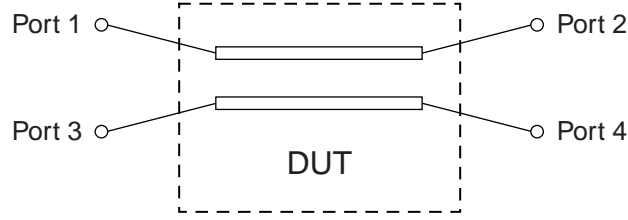
In this derivation we will consider a four-port device. This device could represent two pairs of coupled transmission lines (two differential pairs) or the device could be any arbitrary structure. The extraction of the differential S-parameters is not dependent on the type of device. However, it is extremely important that the extraction is done in a consistent manner with the specific device. In the example of two pairs of differential lines, a consistent manner of port numbering which accompanies the extraction should be adopted. The example used here will be two differential pairs of lines. This derivation and example should only be used for reference. It is left to the engineer to ensure that this method is properly implemented for each specific application.

Figure 8 shows the typical convention for numbering ports for an arbitrary eight-port device. Note that in this case, two different connection points going into the device represent a port. The two different connection points in this case indicated a signal line and its associated ground node. However, the associated ground node connections may be left out. For example, two tightly coupled transmission lines might be shown with only one connection point for each port as in Figure 9. In such cases, the associated ground connections still exist and are implied, but they are not specifically shown.



A-0330

Figure 8: Convention for Numbering Ports



A-0331

Figure 9: Two Differential Transmission Line Pairs with Port Numbering

Given Equation 2 and Equation 3, the wave variables may be re-written as follows:

$$a_n = V_n^+ / \sqrt{Z_{on}}$$

Equation 5: Wave Variables in Terms of Voltages and Characteristic Impedance

Where the subscript “n” is a reference to a specific port. Therefore, Z_{o3} is the reference characteristic impedance at port 3. For a multi-port system, these wave variables are placed in vector form according to their port number. The relationships between each of the wave variables are given in terms of S-parameters. For example, the ratio of the reflected wave variable, “b”, at port 5 to the incident wave variable, “a”, at port 3 is given by the S53 parameter:

$$S_{53} = \left. \frac{b_5}{a_3} \right|_{a_i=0 \text{ for } i \neq 3}$$

Equation 6: Example of S-parameter in Terms of Wave Variables

Note that all of the incident wave variables (except the one of interest – a_3 in this case) must be zero. This is equivalent to having all of the ports terminated by their respective reference impedances. The S-parameter relationship can be given in matrix form where the wave variables are represented in vector form and the S-parameters are in matrix form:

$$[b] = [S][a]$$

Equation 7: S-parameter Definition in Matrix Form

The S-parameters of an eight-port device would be represented as a matrix with eight rows and eight columns as shown in Equation 8.

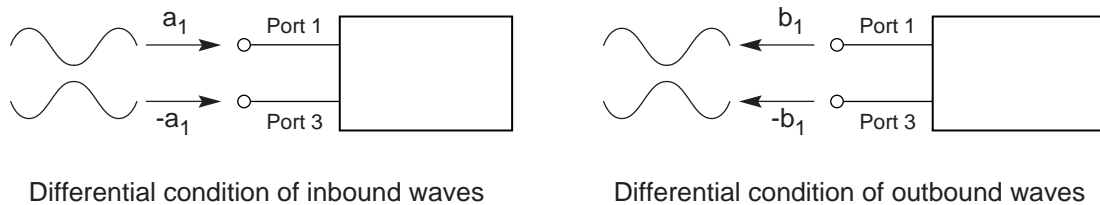
$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \\ b_6 \\ b_7 \\ b_8 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16} & S_{17} & S_{18} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} & S_{26} & S_{27} & S_{28} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} & S_{36} & S_{37} & S_{38} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} & S_{46} & S_{47} & S_{48} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} & S_{56} & S_{57} & S_{58} \\ S_{61} & S_{62} & S_{63} & S_{64} & S_{65} & S_{66} & S_{67} & S_{68} \\ S_{71} & S_{72} & S_{73} & S_{74} & S_{75} & S_{76} & S_{77} & S_{78} \\ S_{81} & S_{82} & S_{83} & S_{84} & S_{85} & S_{86} & S_{87} & S_{88} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \\ a_7 \\ a_8 \end{bmatrix}$$

Equation 8: S-parameter Example of Eight-port Device

9.1.1.2. Derivation of Differential S-parameters

By applying specific conditions at the ports of single ended S-parameters, a set of S-parameters that describe the differential behavior of the device can be obtained. In a similar manner, a set of S-parameters that describe the common mode behavior of the device can also be derived. Therefore, a new set of S-parameters can be derived that include terms for common mode excitation, differential excitation, and terms, which describe conversions between common mode and differential excitation. However, the scope of this document only includes the differential S-parameters. Since the differential S-parameters are just a subset of the overall matrix, differential S-parameter terms are usually identified by using the prefix “DD”—indicating the differential-to-differential subset. For example, the differential equivalent to the single-ended S21 of a device would be DDS21.

To find the differential S-parameters, ports must be paired into differential ports and the wave variables must be adjusted appropriately. For example, port one and port three of a device might be identified as a differential pair with port 1 being defined as the positive terminal and port 3 the negative terminal. Then the corresponding wave variables would be applied as shown in Figure 10.

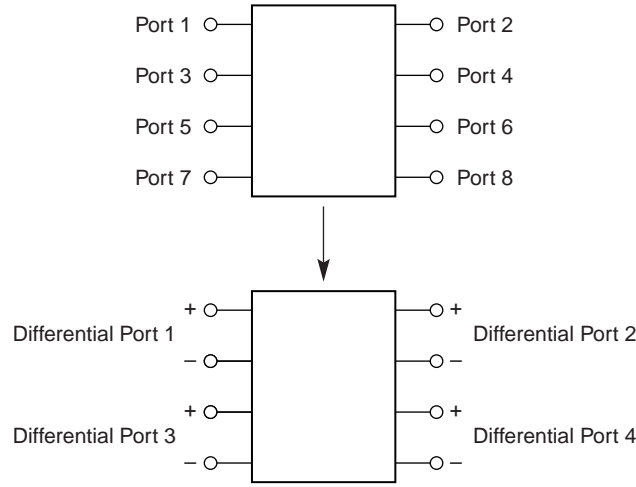


A-0332

Figure 10: Applying Differential Stimulus to Ports 1 and 3

The wave variables at port three are exact copies of the wave variables at port 1, but shifted by 180 degrees in phase. This condition treats the two ports as one differential port by requiring the inbound and outbound waves to be differential. In reality, the waves at the ports may or may not conform to these conditions; however, we are only concerned with the portion of the waves that does conform to this condition.

Equation 8 shows the original single ended parameters for an eight-port device. If the ports are paired such as shown in Figure 11, applying the differential condition according to the mapping gives the relationship shown in Equation 9.



A-0333

Figure 11: Mapping an Eight-port Device into a Differential Four-port Device

$$\begin{bmatrix} b_1 \\ b_2 \\ -b_1 \\ -b_2 \\ b_5 \\ b_6 \\ -b_5 \\ -b_6 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16} & S_{17} & S_{18} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} & S_{26} & S_{27} & S_{28} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} & S_{36} & S_{37} & S_{38} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} & S_{46} & S_{47} & S_{48} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} & S_{56} & S_{57} & S_{58} \\ S_{61} & S_{62} & S_{63} & S_{64} & S_{65} & S_{66} & S_{67} & S_{68} \\ S_{71} & S_{72} & S_{73} & S_{74} & S_{75} & S_{76} & S_{77} & S_{78} \\ S_{81} & S_{82} & S_{83} & S_{84} & S_{85} & S_{86} & S_{87} & S_{88} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ -a_1 \\ -a_2 \\ a_5 \\ a_6 \\ -a_5 \\ -a_6 \end{bmatrix}$$

Equation 9: S-parameter Relationship After Differential Conditions Are Applied

Note that Equation 9 is still referencing the single ended wave variables and S-parameters. This system of equations may be simplified and the individual terms may be combined to form a four-by-four S-parameter matrix representing the differential behavior. Equation 10 shows the differential S-parameter matrix for the eight-port device. The single ended mode wave variables have been replaced with their differential counterparts. For example, “a1” in Equation 10 indicates the differential incident wave at the differential port number 1. However, the S-parameter terms themselves still refer to the single-ended S-parameters shown in Equation 8.

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} (S_{11}-S_{13}-S_{31}+S_{33})(S_{12}-S_{14}-S_{32}+S_{34})(S_{15}-S_{17}-S_{35}+S_{37})(S_{16}-S_{18}-S_{36}+S_{38}) \\ (S_{21}-S_{23}-S_{41}+S_{43})(S_{22}-S_{24}-S_{42}+S_{44})(S_{25}-S_{27}-S_{45}+S_{47})(S_{26}-S_{28}-S_{46}+S_{48}) \\ (S_{51}-S_{53}-S_{71}+S_{73})(S_{52}-S_{54}-S_{72}+S_{74})(S_{55}-S_{57}-S_{75}+S_{77})(S_{56}-S_{58}-S_{76}+S_{78}) \\ (S_{61}-S_{63}-S_{81}+S_{83})(S_{62}-S_{64}-S_{82}+S_{84})(S_{65}-S_{67}-S_{85}+S_{87})(S_{66}-S_{68}-S_{86}+S_{88}) \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}$$

Equation 10: Differential S-parameters for an Eight-port Device

Equation 10 gives a mapping from the single ended S-parameters to the differential S-parameters. Therefore, single-ended measurements may be made on a device and the results can be used to create the differential S-parameter matrix.

9.2. Extraction of Differential S-parameters From Single Ended Measurements

As discussed in Section 9.1.1.2, the differential characteristics of a device can be derived from single ended S-parameter measurements. Section 9.1.1.2 also outlines the theory and derivation that can be applied to general cases and will be used to develop the equations in the following sections. Each of these extractions can be performed by using a spreadsheet or mathematical tool that is capable of handling complex numbers. Calculations involving the addition or subtraction of S-parameters must be done in the complex domain at each frequency point.

9.2.1. Four-port Differential S-parameter Extraction– Insertion Loss

Refer to Section 6.1 for the procedure to perform the required insertion loss measurements using a four-port VNA. The measurement of insertion loss using a four-port VNA only produces one S-parameter file: “4pS21.s1”. The calculation of differential insertion loss from this measurement file is shown in Equation 11. The additions and subtractions should be done at each individual frequency point so that there is one DDS21 result at each frequency point. In addition, the S-parameters must be in the real/imaginary format (the complex domain) before Equation 11 is applied.

$$DDS21 = \frac{1}{2} (S_{21}(4pS21.s1) + S_{43}(4pS21.s1) - S_{41}(4pS21.s1) - S_{23}(4pS21.s1))$$

Equation 11: Calculation of Insertion Loss Using Four-port Measurement Files

Where “ $S_{21}(4pS21.s1)$ ” indicates the S21 parameter of the “4pS21.s1” file. The result of Equation 11 is a complex value for DDS21 at each measured frequency point. These complex values must be converted into units of dB for comparison to the connector specification requirements by using Equation 12.

$$DDS21(dB) = 20 * \log_{10} \left(\sqrt{\text{Re}(DDS21)^2 + \text{Im}(DDS21)^2} \right)$$

Equation 12: Conversion of the Complex Values of DDS21 into Units of dB

Where the function “Re(DDS21)” is the real part of DDS21 and the function “Im(DDS21)” is the imaginary part of DDS21.

9.2.2. Two-port Differential S-parameter Extraction–Insertion Loss

Refer to Section 6.2 for information on performing the appropriate single ended measurements. There are four S-parameter data files which are used for the extraction of DDS21: “J04_J37.s1”, “J04_J43.s1”, “J09_J43.s1”, and “J09_J37.s1”. Equation 13 should be used at each frequency point of the data files to compute the differential insertion loss.

$$DDS21 = \frac{1}{2} (S_{21}(J04_J37.s1) + S_{21}(J09_J43.s1) - S_{21}(J04_J43.s1) - S_{21}(J09_J37.s1))$$

Equation 13: Calculation of DDS21 from Single-ended S-parameter Data Files

Where “ $S_{21}(J04_J37.s1)$ ” indicates the S21 parameter of the file labeled J04_J37.s1. Each of these parameters is complex valued so that the real parts of each must be added and subtracted and the imaginary parts must also be added and subtracted to form the final DDS21 parameter (which is also complex valued).

Finally, Equation 14 is applied to the resulting DDS21 parameter at each frequency point to convert the complex valued parameter into units of dB.

$$DDS21(dB) = 20 * \log_{10} \left(\sqrt{\text{Re}(DDS21)^2 + \text{Im}(DDS21)^2} \right)$$

Equation 14: Conversion of DDS21 into Units of dB

Where the function “Re(DDS21)” is the real part of DDS21 and the function “Im(DDS21)” is the imaginary part of DDS21.

9.2.3. Four-port Differential S-parameter Extraction–Return Loss

Refer to Section 7.1 for the detailed measurement procedure of return loss using a four-port VNA. The measurement only produces one data file: “4pS11.s1” which is used in this calculation. The following calculation must be performed with the S-parameters in the complex domain at each individual frequency point before conversion into units of dB. Equation 15 shows the calculation of return loss using the four-port measurement files.

$$DDS11 = \frac{1}{2} (S_{11}(4pS11.s1) + S_{33}(4pS11.s1) - S_{31}(4pS11.s1) - S_{13}(4pS11.s1))$$

Equation 15: Calculation of DDS11 Using the Four-port Measurement Files

Where, for example, “ $S_{11}(4pS11.s1)$ ” signifies the S11 parameter of the “4pS11.s1” file. The final step is to apply Equation 16 at each frequency point to the resulting DDS11 from Equation 15 to obtain the final DDS11 in terms of dB.

$$DDS11(dB) = 20 * \log_{10} \left(\sqrt{\text{Re}(DDS11)^2 + \text{Im}(DDS11)^2} \right)$$

Equation 16: Conversion of DDS11 into Units of dB

9.2.4. Two-port Differential S-parameter Extraction–Return Loss

Refer to Section 7.2 for performing the appropriate two port measurements on the return loss structure. There is only one S-parameter file needed for the extraction–“J04_J09.s1”. As noted in the insertion loss extraction section, since the S-parameters are complex valued, the calculations must be done in the complex domain before converting to units of dB. Equation 17 is used at each frequency point to compute the differential return loss.

$$DDS11 = \frac{1}{2} (S_{11}(J04_J09.s1) + S_{22}(J04_J09.s1) - S_{21}(J04_J09.s1) - S_{12}(J04_J09.s1))$$

Equation 17: Calculation of DDS11 from the S-parameter Measurement Files

Where $S_{11}(J04_J09.s1)$ indicates the S11 parameter of the “J04_J09.s1” data set. Finally, Equation 18 is applied to the resulting DDS11 data set at each frequency point to convert the data into units of dB.

$$DDS11(dB) = 20 * \log_{10} \left(\sqrt{\text{Re}(DDS11)^2 + \text{Im}(DDS11)^2} \right)$$

Equation 18: Conversion of the Complex Valued DDS11 into Units of dB

The function “ $\text{Re}(DDS11)$ ” gives the real part of the parameter DDS11 and the function “ $\text{Im}(DDS11)$ ” gives the imaginary part of the DDS11 parameter

9.2.5. Four-port Differential S-parameter Extraction–NEXT

Refer to Section 8.2.1 for the NEXT measurement procedure. After the four port measurements are completed, there should be four S-parameter data files: “4pS31.s1”, “4pS51.s1”, “4pS71.s1”, and “4pS91.s1”. The addition and subtraction of S-parameters should be done in the complex format before converting into units of dB. The required calculation for near-end crosstalk for the four-port measurement files is given in Equation 19. This calculation should be applied at each individual frequency point given.

$$\begin{aligned}
 DDNEXT = & \frac{1}{2}(S_{43}(4pS31.s1) + S_{21}(4pS51.s1) + S_{21}(4pS71.s1) + S_{43}(4pS91.s1)) \\
 & + \frac{1}{2}(S_{21}(4pS31.s1) + S_{43}(4pS51.s1) + S_{43}(4pS71.s1) + S_{21}(4pS91.s1)) \\
 & - \frac{1}{2}(S_{41}(4pS31.s1) + S_{23}(4pS51.s1) + S_{23}(4pS71.s1) + S_{41}(4pS91.s1)) \\
 & - \frac{1}{2}(S_{23}(4pS31.s1) + S_{41}(4pS51.s1) + S_{41}(4pS71.s1) + S_{23}(4pS91.s1))
 \end{aligned}$$

Equation 19: Calculation of DDNEXT Using Four-port Measurement Files

Where, for example, “ $S_{43}(4pS31.s1)$ ” is the S_{43} parameter in the “4pS31.s1” measurement file. The final step is to apply Equation 20 at each frequency point on the DDNEXT result from Equation 19 to obtain the final result in units of dB.

$$DDNEXT(dB) = 20 * \log_{10} \left(\sqrt{\text{Re}(DDNEXT)^2 + \text{Im}(DDNEXT)^2} \right)$$

Equation 20: Conversion of DDNEXT into Units of dB

9.2.6. Two-port Differential S-parameter Extraction–NEXT

Refer to Section 8.2.2 for the procedure to perform the required two port measurements on the NEXT test structure. After the measurements are performed, there are a total of 16 data files. As noted in previous extraction sections, the S-parameter data is complex valued and therefore, the addition or subtraction of two S-parameters must be done in the complex domain and then converted to units of dB. The required calculation for near-end crosstalk for the two-port measurement files is given in Equation 21. This calculation should be applied at each individual frequency point given.

$$\begin{aligned}
 DDNEXT = & \frac{1}{2}(S_{21}(J80_J73.s1) + S_{21}(J78_J85.s1) + S_{21}(J78_J83.s1) + S_{21}(J80_J75.s1)) \\
 & + \frac{1}{2}(S_{21}(J78_J71.s1) + S_{21}(J80_J88.s1) + S_{21}(J80_J86.s1) + S_{21}(J78_J72.s1)) \\
 & - \frac{1}{2}(S_{21}(J78_J73.s1) + S_{21}(J80_J85.s1) + S_{21}(J80_J83.s1) + S_{21}(J78_J75.s1)) \\
 & - \frac{1}{2}(S_{21}(J80_J71.s1) + S_{21}(J78_J88.s1) + S_{21}(J78_J86.s1) + S_{21}(J80_J72.s1))
 \end{aligned}$$

Equation 21: Calculation of DDNEXT Using S-parameter Measurement Files

Where, for example, “ $S_{21}(J80_J73.s1)$ ” indicates the S21 parameter in the “J80_J73.s1” file.

Finally, Equation 22 is used at each frequency point to convert the DDNEXT result from Equation 21 into units of dB.

$$DDNEXT(dB) = 20 * \log_{10} \left(\sqrt{\text{Re}(DDNEXT)^2 + \text{Im}(DDNEXT)^2} \right)$$

Equation 22: Conversion of DDNEXT into Units of dB

In Equation 22, the function “Re(DDNEXT)” returns the real part of the DDNEXT complex number and the function “Im(DDNEXT)” returns the imaginary part of DDNEXT.